**Technical assessment for**

**Tree Intercropping**

Sector: Food

Agency Level: Farmer

Keywords: Biosequestration, Annual Crop Production, Agroforestry

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# Executive Summary

Project Drawdown defines *tree intercropping* as a suite of agroforestry systems that deliberately grow trees together with annual crops in a given area at the same time. This solution replaces conventional annual crop production on degraded cropland.

The main purpose of growing trees varies across different types of *tree intercropping*. Some systems use trees to support annual crop production (e.g. intercropping with nitrogen-fixing trees, as in evergreen agriculture) or as protective systems against erosion, flooding, or wind damage (e.g. hedgerows, riparian buffers, and windbreaks). In other systems, the trees are crops themselves (e.g. strip intercropping of annual crops with timber or fruit trees). *Tree intercropping* is an important strategy for producing annual crops while sequestering carbon in soils and aboveground biomass. It provides important co-benefits, including erosion control, riparian stabilization, soil fertility improvements, and, in many cases, increased yields. *Tree intercropping* systems are widely adopted by tropical smallholders but are also practiced on millions of hectares of cropland in highly mechanized regions of China and Europe.

In Drawdown’s Agroecological Zone model *tree intercropping* is established on degraded or marginalized grazing land. The current extent of *tree intercropping* systems is estimated to be about 248 million hectares globally. Future adoption potential was modeled based on global, regional and national historical adoption trends, and is constrained principally by high establishment costs and water, as well as requirement low recognition of the solution’s potential which lead to a lack of incentives for farmers. For instance, climate mitigation literature often fails to differentiate between *tree intercropping* and other "agroforestry" cropping systems such as *multistrata agroforestry* and *silvopasture*, grouping these systems together.

Adoption is determined at the farmer- or landowner-level, and impacts were modeled for C sequestration, establishment and operational costs and profitability, based on case-study data from peer reviewed literature.

Under the projected *Plausible* Scenario, total adoption is 318 million hectares in 2050. The sequestration impact of this scenario is 13.71 Gt CO2 eq. by 2050, with a net profit margin of US$481.31 billion. Under the *Drawdown* Scenario, total adoption is 455.90 million hectares in 2050. The sequestration impact under this scenario is 21.05 Gt of CO2 eq. by 2050, with net profit margin of US$716.94 billion. Under the *Optimum* Scenario, projected total adoption is 440.50 million hectares in 2050. The sequestration impact under this scenario is 23.55 Gt of CO2 eq. by 2050, with net profit margin of US$224.30 billion.

# Literature Review

Tree intercropping systems are integrated agricultural systems which combine tree and annual crops; they can take extremely varied and diverse forms and can be applied across a range of climates and at different scales. Increased recognition of their many environmental and economic benefits, particularly in the context of climate change and deforestation, coupled with improved national or regional incentive mechanisms, is likely to significantly increase future adoption rates of this solution at the farmer / landowner agency level.

## State of the Practice

Agroforestry, as defined by the World Agroforestry Center, is “a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels”. Drawdown’s *tree intercropping* solution focuses on agroforestry systems in which trees are deliberately grown together with agricultural annual crops in a given area at the same time. Establishment can entail the procurement and planting of tree seedlings in already existing annual-cropping systems, or the integration of both annual and tree components during initial preparation of a field. In these systems, both trees and crops have added potential to sequestrate carbon (C) over time. Agroforestry systems with alternating tree and crop rotation that trees and crops were not considered due to their low potential for C sequestration (Wolz et al., 2018)

Annual row crops dominate agriculture around the world and have considerable negative environmental impacts, including significant greenhouse gas emissions. Transformative land-use solutions are necessary to mitigate climate change and restore critical ecosystem services. Alley cropping (AC)—the integration of trees with crops—is an agroforestry practice that has been studied as a transformative, multifunctional land-use solution. In the temperate zone, AC has strong potential for climate change mitigation through direct emissions reductions and increases in landuse efficiency via overyielding compared to trees and crops grown separately. In addition, AC provides climate change adaptation potential and ecological benefits by buffering alley crops to weather extremes, diversifying income to hedge financial risk, increasing biodiversity, reducing soil erosion, and improving nutrient- and water-use efficiency. The scope of temperate AC research and application has been largely limited to simple systems that combine one timber tree species with an annual grain. We propose two frontiers in temperate AC that expand this scope and could transform its climate-related benefits: (i) diversification via woody polyculture and (ii) expanded use of tree crops for food and fodder. While AC is ready now for implementation on marginal lands, we discuss key considerations that could enhance the scalability of the two proposed frontiers and catalyze widespread adoption (Kim et al., 2016; Wolz et al., 2018).

Tree intercropping takes different forms in different parts of the world (Table 1). Some systems are equally focused on both the tree crop production and annual crop production (e.g. strip intercropping), others use perennials to support annual crop production (e.g. alley cropping) or as protective systems against erosion, flooding, or wind damage (e.g. hedgerows, riparian buffers, windbreaks). There is wide variation in the proportion of trees in different tree intercropping system, and this is reflected neither in the FAO nor the World Agroforestry Centre’s current definitions of agroforestry and tree intercropping, which do not specify tree cover ranges. Drawdown’s definition includes systems with 10-20% tree cover (den Herder, 2017).

Table .. Examples of common tree-intercropping systems

|  |  |
| --- | --- |
| System | Definition and Examples |
| Agrisilvicultural | Crops and trees are simultaneously cultivated on the same land. |
| Strip Intercropping | Tree crops are grown in rows, usually alternating with annual crops. The tree crops typically produce timber or food. |
| Alley Cropping | Tree crops are grown in rows, usually alternating with annual crops. Tree crops are usually rows of coppiced, nitrogen-fixing trees primarily present to support the annual crops. |
| Hedgerows | A line of closely spaced shrubs and tree species is planted and trained to form a barrier or to mark the boundary of an area. Also referred to as boundary planting, shelterbelts or live fences. |
| Riparian Buffer | Strips of perennial vegetation (tree/shrub/grass) planted between croplands/pastures and streams, lakes, wetlands, ponds, etc. |
| Windbreaks | Trees, or sometimes shrubs or other perennials, are planted in long strips against prevailing winds to protect crops, livestock, and people |
| Improved fallows | Trees (generally legumes, or nitrogen-fixing species) are planted to enrich depleted soil |

Tree intercropping has great potential for C sequestration. Trees can store C in above-and belowground biomass for extended period of times and allocate much greater amounts of C in belowground biomass compared to annual crops. Soil C storage could also be increased due to increased litterfall, root exudates and root turnover.

Intercropping of trees and crops has been practiced for thousands of years, and has traditionally been a key element of global agricultural landscapes (Smith, 2010). For example, the practice of intercropping different kinds of cereals, fodder crops or vineyards with productive trees such as olives, fruit, timber or nut trees has been implemented for several thousand years in Europe (Eichhorn et al., 2006). Since the 1970s, a push for more ecologically and socially friendly natural resource management has contributed to practices such as agroforestry and tree intercropping gaining momentum (Van Alfen, 2014). During recent decades, the development and adoption of tree intercropping has been driven by the multiple benefits that the system could bring, including environment conservation, economic benefits and improved livelihoods.

***Variations Between Climates***

(Wolz et al., 2018) conducted a global review of tree intercropping systems, including 1,244 publications from 77 countries. Their results showed that the typology and composition of tree intercropping systems varies substantially between climates (see Table 2). Tropical tree intercropping focuses on multipurpose tree species which can simultaneously contribute to biomass accumulation, food production, nitrogen-fixing and annual crop facilitation. Understory crops are generally annual or perennial food crops. In subtropical systems the primary role of trees is biomass provision and food production, with nitrogen fixation frequent but not as ubiquitous as in the tropics. Understory crops are mostly comprised of annual food crops. In temperate systems, tree species contribute to biomass accumulation 82% of the time. They can also contribute to food production, but nitrogen fixation benefits is scarce. The understory consists mostly of annual food crops, with some perennial forage production.

Table 1.2: Variations in Tree Intercropping Practice Between Climates

Adapted from (Wolz et al., 2018)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Climate** | **Most common tree genera** | **Priority tree-functions** | **Frequency of N-fixation in tree component** | **Intercrop functions** |
| Tropical | *Leucaena, Gliricidia* | biomass, food, crop facilitation | high | annual and perennial food crops |
| Subtropical | *Eucalyptus* | biomass, food | medium | annual food crops |
| Temperate | *Juglans, Populus* | biomass | low | mostly annual food crops, some forages |

Table .: Mean aboveground biomass and soil organic carbon sequestration rates by region in common tree intercropping systems

Adapted from Tables 3 & 4 in (Feliciano et al, 2018), which was published after the publication of *Drawdown.*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Continent** | **Agroforestry System Type** | **Aboveground Biomass Sequestration Rate t/ha/yr** | | | **Soil Organic Carbon Sequestration Rate t/ha/yr** | | |
| **Mean** | **Variance** | **# of Observations** | **Mean** | **Variance** | **# of Observations** |
| Africa | Agrisilvicultural | .88 | .14 | 5 | .32 | 2.42 | 25 |
| Hedgerows | - | - | - | -.98 | .37 | 2 |
| Improved fallows | 12.95 | 20.12 | 17 | 1.91 | 3.42 | 17 |
| Asia | Agrisilvicultural | 1.13 | 2.52 | 4 | .27 | - | 1 |
| Improved fallows | 2.9 | 2.52 | 4 | - | - | - |
| Europe | Agrisilvicultural | - | - | - | 6.7 | - | 1 |
| Latin America | Agrisilvicultural | 2.94 | 5.56 | 6 | 1.73 | 3.07 | 13 |
| Hedgerows | 9.14 | 54.72 | 5 | - | - | - |
| Improved fallows | 5.55 | 5.45 | 2 | - | - | - |
| North America | Hedgerows | 1.12 | - | 1 | - | - | - |
| Agrisilvicultural | - | - | - | .39 | 10.99 | 12 |

***High Lifetime Carbon Stocks***

Carbon sequestration refers to carbon fixed from the atmosphere over a set period of time. Carbon stocks, on the other hand, are a measure of total carbon accumulated in an ecosystem over the course of its lifetime, after years of carbon sequestration. The Drawdown model does not account for existing carbon stocks and all calculations include only annual sequestration rates in soils and vegetation biomass.

It is nevertheless worth exploring the differences between stocks in various farming systems as they differ widely. Carbon stocks accumulate both in soils (soil organic carbon, or SOC) and in above- and below-ground vegetation biomass. Tree intercropping systems show 3-4 times higher lifetime SOC stocks than improved annual cropping systems alone (Figure 1). A recent review of C storage capacity in different cropping systems in Africa (Corbeels et al., 2018) indicates high variability in C stocks reported in current studies; indeed the aboveground biomass of tree intercropping systems has been documented to be as high as 120 t/ha, though average reported figures are usually lower (Table 4). Aboveground C stocks, though modest compared to those measured in multistrata agroforestry and silvopasture (Corbeels et al., 2018), are nevertheless impressive when compared to the essentially absent biomass stocks in annual cropping systems.

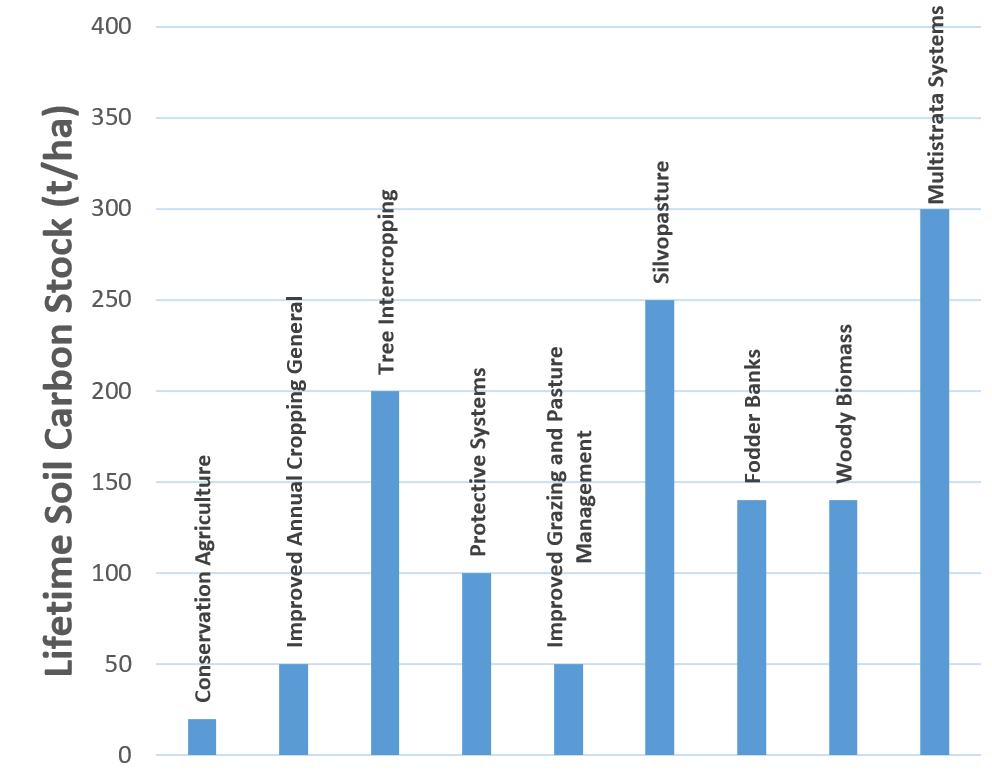


Figure .: Lifetime potential soil carbon stocks of various carbon-sequestering agriculture systems compared. Adapted from (Toensmeier, 2016)

Table .: Lifetime C stocks in aboveground biomass of common types of agroforestry systems

Adapted from (Lasco, 2006; Montagnini, 2015). Note that these are carbon stocks, not annual sequestration rates.

|  |  |  |
| --- | --- | --- |
| **System** | **Climate** | **Carbon Stocks t/ha** |
| Taungya | Humid tropics, no dry season | 35 |
| Alley cropping | Humid tropics, short dry season | .65 |
| Taungya | Humid tropics, short dry season | 58-120 |
| Alley cropping | Tropical with dry summer | 30 |
| Tree intercropping | Subtropical with no dry season | 7-23 |
| Agrisilviculture (Africa) | Humid tropical highlands | 29-53 |
| Agrisilviculture (S. America) | Humid tropical lowlands | 39-102 |
| Agrisilviculture (S. America) | Dry lowlands | 39-195 |
| Agrisilviculture (SE Asia) | Humid tropical | 12-228 |
| Agrisilviculture (SE Asia) | Dry lowlands | 68-81 |
| Improved fallow (2 years, E. Africa) | - | 27-44 |
| Improved fallow (1 year, E. Africa) | - | 7-21 |
| Improved fallow (6 years, SE Asia) | - | 4-64 |
| Alley cropping (SE Asia) | - | 1.5-4.5 |

***Environmental & Socioeconomic Benefits***

In addition to C sequestration, tree intercropping provides a range of ecological, economic and social benefits. Inclusion of trees on farms has been shown to provide a range of ecological services including enhanced soil structure and water infiltration (Lal, 2014; Pimentel et al., 2012), reduced soil erosion on slopes (Kinama et al., 2007), reducing wind or flood damages to annual crops (Simelton et al., 2015), biodiversity conservation (Clough et al., 2009) and enhanced soil fertility (Moreno et al., 2007; Wartenberg et al., 2019). Trees are deeper rooted compared to annual crops, and therefore could optimize the utilization of resources. Trees could bring water and nutrients from deeper soils layers to annual crops (Van Noordwijk and Purnomosidhi, 1995). Nitrogen-fixing tree species could bring extra nitrogen inputs, which are especially beneficial in developing countries where fertility inputs are limited. For instance, in Malawi, the leguminous nitrogen-fixing *Faidherbia albida*was found to greatly enhance maize yield (*Zea mays*) by up to 280% under its canopy compared with the zone outside the canopy (Saka et al., 1994).

Tree intercropping further enhances resilience to climate change and improves food security and livelihoods. Trees can increase rainwater infiltration, reducing downstream flooding and recharging groundwater (de Leeuw, 2017), though they can also compete for water with annual crops. Trees provide microclimate regulation and can also impact local water cycles (Ellison et al., 2017), providing protection and reducing the impacts of weather extremes such as droughts or heavy rain (Schoeneberger et al., 2012). In addition, the increased diversity on farms reduces farmers’ dependency on a single staple crop and protects farmers against crop failure (de Leeuw, 2017). Trees produce nutritious fruits and nuts that could diversify the nutrition intake for smallholder farmers. Trees could also produce fuel woods, fodder, construction materials and medicinal products, and greatly diversify the income sources and raise farm incomes for smallholder farmers.

Tree intercropping has been practiced for thousands of years in some regions. Further adoption of tree intercropping could contribute to the perpetuation of indigenous ecological knowledge and social and cultural values (Nair et al., 2017).

***Drawbacks and Tradeoffs***

Trees take time to establish and the financial breakeven points for tree crops is generally delayed by several years following establishment. This leads to a delayed return to investment which could inhibit adoption for smallholder farmers who have to cope with this net financial loss during the transition period. Integration of trees into annual cropping systems are thus long-term investments. A lack of stable and secure land-tenure and land-access rights is likely to further inhibit farmers from investing in trees.

Tree intercropping systems should be properly designed to maximize the profits from both the trees and annual crop components of the systems. Inappropriate planting designs or management practices might lead to declines in yields and profits. For example, in alley cropping or strip cropping systems, the spacing between trees and the selection of crop varieties need to be carefully designed to ensure species utilize unique ecological niches and minimize competition. Successfully managing trees in addition to annual crops is a knowledge-intensive practice, which requires landowners to have access to relevant information, for instance through agricultural extension networks.

## Adoption Path

Current adoption of tree intercropping systems is estimated at about 248 Mha. This figure is likely to increase due to the practice’s rapidly increasing recognition and integration into strategies to address deforestation and land degradation developed by international frameworks and initiatives. Increased recognition of the tangible benefits of the practice remains limited by a lack of data, and increased adoption remains hampered by economic challenges and a lack of awareness and technical training for farmers. Policies addressing high initial costs through flexible financing approaches would contribute to increased adoption, as would the development and dissemination of specialized mechanization technologies designed to reduce labor intensity in tree intercropping systems.

### Current Adoption

To date, accurate and comprehensive datasets on the current adoption levels of different forms of tree intercropping do exist. A recent study by (Lal et al., 2018) estimates the total global extent of tree intercropping systems at approximately 600 Mha. A more comprehensive study by (Zomer et al., 2014) uses global remote sensing data to estimate total global cropland with >10%, >20% and >30% tree cover. Given the resolution of satellite data used for the study, this data does not necessarily differentiate between tree intercropping systems and small areas with trees adjacent to cropland and should therefore be taken as a rough estimate. Nevertheless, Drawdown models estimate a global area of 248 Mha under tree intercropping systems with 10-20% canopy cover, based on GAEZ cropland data and tree cover data derived from (Zomer et al., 2014).

Regional data on current adoption of tree intercropping remains similarly scarce, except for Europe, where results from a recent research project focused on agroforestry (AgForward) indicates that the adoption of tree intercropping practices is widespread, and estimates the establishment of tree intercropping on 39% of agricultural land in the region (den Herder, 2017). Nevertheless, globally, despite the widespread and growing integration of trees in annual crop systems, data on adoption remains lacking.

### Trends to Accelerate Adoption

Tree-based cropping systems provide a wide range of benefits including soil and water conservation and carbon sequestration (de Leeuw, 2017; Pimentel et al., 2012). For this reason, tree-intercropping systems have been gaining traction at the international stage as a strategy for “climate-smart” agriculture, landscape restoration and carbon sequestration. Increased interest in and recognition of the potential of such “climate-smart” practices may provide growing opportunities to scale up the adoption of tree intercropping practices (Harvey et al., 2014; Montagnini, 2015).

For instance, agroforestry is recognized within the UNFCCC framework as a mitigation strategy and has in recent years been identified as a significant mitigation option in national strategies such as Rwanda’s Vision 2050 or the EU’s Low Carbon Road Map 2050. Wider integration of agroforestry and tree intercropping into national strategies and frameworks, or into Reduced Emissions from Deforestation and Forest Degradation (REDD+) programs could provide land owners additional incentives to adopt tree intercropping in the agricultural landscape. Increased recognition of the benefits associated with approaches such as Farmer-Managed Natural Regeneration (Abdirizak et al., 2013), which provides farmers with flexible and inexpensive tree intercropping practices that can be adapted to families’ or communities’ needs and resources, provides further opportunities to scale up adoption trends, particularly in degraded landscapes.

### Barriers to Adoption

The development of agroforestry, including tree intercropping, is often inhibited by a lack of supportive legal, policy and institutional arrangements. Policy should be developed to foster the adoption of agroforestry.

* **Raise awareness & technical assistance.** There is a lack of knowledge or understanding of tree intercropping systems among smallholder farmers in resource-poor settings, which leads to resistance towards switching to a different planting system. It is critical to raise awareness on the long-term benefits of incorporating trees on farms. In addition, tree-intercropping systems are usually more knowledge-intensive compared to annual cropping systems. Therefore, strong extension and training services covering variety selection, spacing, and best management practices are needed to promote the adoption of tree intercropping and ensure successful establishment of the systems.
* **Clarification of land-use policy goals and regulations.** In many developing countries, lack of long-term rights to land or trees inhibit farmers from introduction or continuation of agroforestry practices. A secure framework of land tenure does not necessarily mean formal land titling or complete privatization of land to farmers, in many cases customary forms of tenure provide land or tree security and has low administration costs (FAO, 2013). Innovative and inexpensive ways of land-use policy could be developed in different social and ecological contexts.
* **Market development.** Increased income is the strong motive for farmers to adopt agroforestry, while the risks associated with underdeveloped markets might inhibit the adoption. Assistance in identifying and accessing markets and the provision of sound market information for land owners are strong incentives to promote adoption (FAO, 2013).
* **Financial incentives for adoption.** Access to financial assistance such as grants, credit, taxes could help landowners establish tree intercropping systems and overcome the first several years of net economic loss. This is especially true for resource-poor smallholder farmers.
* **Legal incentives for adoption.** Integration of tree intercropping into national legal frameworks will facilitate monitoring and evaluation of the practice and its associated benefits. Improved recognition and integration of tree intercropping practices into existing agricultural regulations will likely facilitate compensation for ecosystem service benefits and provide additional incentives for farmers (Tsonkova et al., 2018).

### Adoption Potential

Projections of the adoption potential of tree intercropping *as such* are quite rare. Total adoption potential in tropical and temperate climates has been estimated at 600-608 Mha (Griscom et al., 2017; Lal et al., 2018).

## Advantages and disadvantages of Tree Intercropping

### Similar Solutions

Tree intercropping is one of many sustainable land management solutions to increase carbon sequestration. Structurally it is similar to other agroforestry-based Drawdown solutions *(multistrata agroforestry, silvopasture, tropical staple tree crops*). Given its potential for replacing conventional annual cropping systems, tree intercropping is however most similar to *conservation agriculture*, which is a suite of agricultural management practices (no-till, diversified rotation and increased land coverage) aimed to increase carbon sequestration in annual cropping systems.

### Arguments for Adoption

Tree intercropping is a solution which bridges some of the trade-offs associated with other agroforestry solutions such as multistrata agroforestry or silvopasture. The tree components in tree intercropping systems still contribute to ecosystem benefits such as microclimate regulation and soil and water conservation, although at lower rates than more tree-intense systems. At the same time, tree intercropping systems are associated with lower costs and less management limitations. Their annual crop component also gives them the potential to directly compete with annual cropping systems.

In comparison with *conservation agriculture,* tree intercropping has much higher C sequestration potentials due to the integration of trees into cropping systems. Tree intercropping systems further bring an additional multitude of ecological, socio-economical and financial benefits compared to *conservation agriculture*. For example, tree intercropping can better conserve biodiversity and provides a protective barrier for lands and people against wind hazards and severe dust dorms.

### Additional Benefits and Burdens

Here this solution is compared with other solutions in the food production cluster for farm, ecosystem, and social impacts. While tree intercropping systems are associated with high start-up costs and a long delayed-profit period, they are also associated with high ecosystem service benefits and medium climate impacts compared to other land-use and food solutions.

Table .Food Production Solutions Comparison: On-Farm Impacts

**Yield Gains:** loss of yield “loss”,no impact “n/a”,1-9% low, 10-24% medium, 25%+ high. **First Cost**: Free is $0**,** Low is $1-100, Medium is $100-500, Expensive is $500+. **Net Profit Margin:** Low is $0-100/ha, Medium is $100-500, High is $500+. **Delayed Profit Period:** Short is 0-2, Mid is 3-6, Long is 6+

|  | **Yield Gains** | **Startup Cost** | **Net Profit** | **Delayed Profit Period** |
| --- | --- | --- | --- | --- |
| Conventional cropping | n/a | n/a | Medium | n/a |
| Conventional grazing | n/a | n/a | Medium | n/a |
| Conservation agriculture | Low | Medium | High | Mid |
| Farmland restoration | High | Medium | Medium | Short |
| Farm water use efficiency | n/a | Expensive | Medium | Short |
| Improved rice | Loss | Free | High | Mid |
| Managed grazing | Medium | Medium | Medium | Mid |
| Multistrata agroforestry | n/a | Expensive | High | Long |
| Nutrient management | n/a | Free | Low | Short |
| Regenerative agriculture | Low | Medium | High | Mid |
| Silvopasture | Medium | Expensive | High | Long |
| System of Rice Intensification | High | Free | High | Mid |
| Tree intercropping | **Low** | **Expensive** | **Medium** | **Long** |
| Tropical staple tree crops | High | Expensive | High | Long |
| Women smallholders | high | Free | High | Short |

*Table 1.6 Food Production Solutions Comparison: On-Farm Impacts Social and Ecological Impacts*

**Ecosystem Services** is subjective based on impacts on biodiversity, water quality, etc. **Social Justice Benefits:** Is solution Targeted to disadvantaged producers like smallholders and women, Relevant to them, or Not Applicable (n/a). **Climate Impacts per Hectare:** Low 0-3.7 t CO2-eq/ha/yr (0-1tC),Medium 3.8-11.0 t CO2-eq/yr (1-3 tC), High 11.1+ tCO2-eq/yr (3+tC). **Global Adoption Potential:** Low 0-100Mha, Medium 101-500 Mha, High 500+ Mha

|  | **Ecosystem Services** | **Social Justice Benefits** | **Climate Impact/ha** | **Global Adoption Potential** |
| --- | --- | --- | --- | --- |
| Conventional cropping | n/a | n/a | n/a | n/a |
| Conventional grazing | n/a | n/a | n/a | n/a |
| Conservation agriculture | Low | Relevant | Low | Medium |
| Farmland restoration | Medium | Relevant | Medium | Medium |
| Farm water use efficiency | Low | Relevant | Low | Medium |
| Improved rice | Medium | Relevant | high | Low-medium |
| Managed grazing | Low | Relevant | Low | Medium-high |
| Multistrata agroforestry | High | Relevant | High | Low |
| Nutrient management | Medium | Relevant | Low | High |
| Regenerative agriculture | Medium | Relevant | Low | Medium-high |
| Silvopasture | High | Relevant | High | Low-medium |
| System of Rice Intensification | Medium | Targeted | Medium | Low |
| **Tree intercropping** | **High** | **Relevant** | **Medium** | **Medium** |
| Tropical staple tree crops | Medium | Relevant | High | Low-medium |
| Women smallholders | n/a | Targeted | Low | Low |

# Methodology

## Introduction

Project Drawdown’s models are developed in Microsoft Excel using standard templates that allow easier integration with each other since integration is critical to the bottom-up approach used. The template used for this solution was the Land Model, which accounts for:

1. Sequestration of carbon dioxide from the atmosphere into plant biomass and soil; and
2. Reduction of emissions for a solution relative to a conventional practice.

These practices are assumed to use land of a specific type that may be shared across several solutions. Actual and maximum possible adoptions are therefore defined in terms of land area (million hectares). The adoptions of both conventional and solution were projected for each of several Drawdown scenarios from 2015 to 2060 (from a base year of 2014) and the comparison of these scenarios with a reference (for the 2020-2050 segment[[1]](#footnote-1)) is what constituted the results.

Drawdown’s *tree intercropping* solution provides comparison to conventional agricultural systems without trees. Although data on adoption rates and climate/financial variables at regional scales is limited, current adoption was estimated at about 248 million hectares globally (Zomer et al., 2014). Model work is based on BIOSEQ V0.4.6.

*Agency Level*

The farmer is selected as the agency level for this solution. Though certainly other agents can, do, and should play an important role in this solution, the decision-maker on the ground is the most critical player in implementation.

## Data Sources

Data for the model was drawn from a review of 68 peer-reviewed publications, grey literature (e.g government reports and university financial resources for farmers), as well as public sector sources such as the FAO’s online statistical service. Total available land for tree intercropping future adoption is calculated by the Drawdown model based on projections of increased tree inclusion on existing global cropland area, excluding regions under arctic and boreal climate conditions.

## Total Available Land

Drawdown’s agricultural production and land use model approach defines the Total Land Area for each solution as the area of land (in million hectares) suitable for adoption a given solution. Determining this figure for Total Land Area is a two-part process.

1. First, the technical potential is determined, based on current land cover or land use; the suitability of climate, soils, and slopes; and degraded or non-degraded status. Relevant data on global land-use and availability is acquired from Global Agro-Ecological Zones database, developed by the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA).
2. In the second stage, land is allocated using the Drawdown Agro-Ecological Zone model, based on priorities for each class of land. The Drawdown Land-Use Model categorizes and allocates land according to agro-ecological zones based on the following factors: thermal climate, moisture regimes, soil quality, slope, cover type, and degradation status. These characteristics influence the suitability of different practices, and solution adoption scenarios are restricted by one or more of these factors (see Section 2.7 for more details).

The total land allocated for each solution is capped at the solution’s maximum adoption in the *Optimum* Scenario. Thus, Drawdown estimates of total available land are very conservative as final allocation numbers are less than those determined purely through technical potential. Drawdown new adoption potential for tree intercropping is modeled specifically on existing degraded cropland in temperate and tropical climates. This area has been allocated to avoid overlap with other solutions such as *conservation agriculture*, *multistrata agroforestry* and *silvopasture*.

Based on existing data regarding available degraded cropland, as well as land allocation as determined through the Drawdown Agro-Ecological Zone model, the maximum area allocated to tree intercropping is 464 million hectares. This figure is used throughout the Drawdown model for this solution. Current adoption of *tree intercropping* is estimated at 248 million hectares (Zomer et al., 2014). There are estimates of higher areas under *tree intercropping* in existing literature; however, to avoid double-counting, Drawdown estimates only consider areas dedicated to *tree intercropping* as defined in Section 1, excluding annual cropping areas with sparse trees. These areas are included under Drawdown’s *conservation agriculture*, *regenerative agriculture*, *improved rice cultivation*, and *system of rice intensification* solution.

## Adoption Scenarios

Two different types of adoption scenarios were developed: 1) a Reference (REF) Case which was considered the baseline, where not much changes in the world; and 2) a set of Project Drawdown Scenarios (PDS) with varying levels of ambitious adoption of the solution. Published results show the comparison of one PDS to the REF, and therefore focus on the change to the world relative to a baseline.

Drawdown’s future adoption were developed based on a) historical changes in the percent of agricultural land under 10-20% between 2000 – 2010, as determined by (Zomer et al., 2014); b) UK projections of future land-use change by 2050, as reported by (Thomson et al., 2018); and c) current estimates of tree intercropping adoption in the EU based on calculations in (den Herder, 2017). Details for the seven resulting scenarios are given below:

1. ***Custom adoption scenario one***: Linear projection based on current global increase rates of tree cover greater than 10% on cropland, as calculated based on (Zomer et al., 2014) data. Percent of agricultural land under >10% and >20% tree cover in 2000 and 2010 was calculated. We compared this to total global cropland (1473 Mha according to GAEZ zones) and calculated a global increase in 10-20% tree cover on cropland of 6.4% from 2000 - 2010, which was converted to an annual increase rate of 0.64 % for this scenario.
2. ***Custom adoption scenario two***: Linear projection based on current global increase rates of tree cover greater than 10% on cropland, as calculated based on (Zomer et al., 2014) data. Percent of agricultural land under >10% and >20% tree cover in 2000 and 2010 was calculated. We compared this to total global cropland (1473 Mha according to GAEZ zones) and calculated a global increase in 10-20% tree cover on cropland of 6.4% from 2000 - 2010, which was doubled and converted to an annual increase rate of 1.28 % for this scenario.
3. ***Custom adoption scenario three***: Linear projection based on the projected rate of 5% conversion of remaining cropland by 2050 as reported by (Thomson et al., 2018) for UK projections of future land-use change. Total remaining global cropland in 2014 is estimated at 1134 Mha, which was calculated based on the difference between total current cropland of 1473 Mha and the total global area already under tree intercropping.
4. ***Custom adoption scenario four***: Linear projection based on the projected rate of 10% conversion of remaining cropland by 2050 as reported by (Thomson et al., 2018) for UK projections of future land-use change. Total remaining global cropland in 2014 is estimated at 1134 Mha, which was calculated based on the difference between total current cropland of 1473 Mha and the total global area already under tree intercropping.
5. ***Custom adoption scenario five***:Linear projection estimating a medium current adoption rate of 20% of tree intercropping on remaining global cropland. Total remaining global cropland in 2014 is estimated at 1134 Mha, which was calculated based on the difference between total current cropland of 1473 Mha and the total global area already under tree intercropping.
6. ***Custom adoption scenario six***:Linear projection based on current adoption rate of tree intercropping on cropland in the EU, which is 39% as reported in (den Herder, 2017). This rate was applied to all current remaining global cropland by 2050. Total remaining global cropland in 2014 is estimated at 1134 Mha, which was calculated based on the difference between total current cropland of 1473 Mha and the total global area already under tree intercropping.

### Reference Case / Current Adoption[[2]](#footnote-2)

Current adoption of *tree intercropping* is estimated at 248 Mha. This value was determined based on GAEZ cropland data and tree cover data derived from (Zomer et al., 2014).

### Project Drawdown Scenarios

Three Project Drawdown scenarios (PDS) were developed for each solution, to compare the impact of an increased adoption of the solution to a reference case scenario, being:

#### Plausible Scenario – A conservative approach is adopted for the plausible scenario, and future growth of the solution is estimated based on the “average of all” custom adoption scenarios as listed above.

#### Drawdown Scenario – For the drawdown scenario, an ambitious approach is adopted, and future growth of the solution is estimated based on the “high of all” custom adoption scenarios as listed above

#### Optimum Scenario – or the optimum scenario, custom adoption scenario that is giving maximum growth based on the existing prognostication is considered, which is represented by the “custom scenario 6”.

## Inputs

### Climate Inputs

Carbon sequestration rates of *tree intercropping*are set at 1.66 tons of carbon per hectare per year. This is the result of meta-analysis of 15 data points from 9 sources.

**Table 2.1 Climate Inputs**

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Biosequestration | *tC/ha/yr* | 0.4 – 2.9 | 1.66 | 15 | 9 |

Note: Project Drawdown data set range is defined by the low and high boundaries which are respectively 1 standard deviation below and above the mean of the collected data points[[3]](#footnote-3).

*Modeling Saturation*

Biosequestration does not have limitless potential. In most cases, there is a maximum amount of carbon that can be stored in soils and aboveground perennial biomass before they become saturated. Biosequestration continues after saturation but is offset by more or less equal emissions. In most cases soils, and biomass can return to their approximate pre-agricultural or pre-degradation levels of carbon. This takes anywhere between 10-50 years in agricultural cases, and sometimes somewhat longer in the case of ecosystems like forests. Data about saturation time is very limited.

The Drawdown land model takes the conservative approach that all land units currently adopted for agricultural solutions (including tree intercropping) have already achieved saturation and will not be contributing additional sequestration. New adopted land is assumed to sequester for at least 30 years before achieving saturation.

Note that there are some important exceptions to saturation. Certain ecosystems continue to sequester soil carbon for centuries, notably peatlands and coastal wetlands. Some scientists argue that tropical forests can continue to sequester carbon at a slower rate after saturation. The addition of biochar to saturated soils may be able to overcome this constraint, as does the use of biomass from bamboo or afforestation in long-term products like buildings.

### Financial Inputs

First costs are estimated at US$968.12 per hectare, based on meta-analysis of 11 data points from 8 sources. For all agricultural solutions it is assumed that there is no conventional first cost, as agriculture is already in place on the land. Net profit is US$122.79 (weighted based on the total degraded cropland area to total cropland area) per hectare per year as the solution is allocated on the degraded cropland area, compared to US$491.81 which comes from practice of conventional cropping on non-degraded area.

**Table 2.2 Financial Inputs for Conventional Technologies**

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| First costs (Conventional) | *US$2014/ha* | $0 | $0 | n/a | n/a |
| Net profit (Conventional) | *US$2014/ha* | $229.05 - $756.58 | $122.79 | 67 | 33 |
| Operating Cost (Conventional) | *US$2014/ha* | $475.67 - $1,314.61 | $895.14 | 57 | 25 |

**Table 2.3 Financial Inputs for Solution**

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| First costs (Solution) | *US$2014/ha* | $57.84 -$1,878.39 | $968.12 | 11 | 8 |
| Net profit (Solution) | *US$2014/ha* | $173.46 - $313.30 | $243.38 | 4 | 4 |
| Operating Cost (Solution) | *US$2014/ha* | $844.39 - $1,241.65 | $1,043.02 | 16 | 10 |

Farmers and ranchers transitioning to carbon-friendly practices face a period of reduced income. This reflects an individual learning curve, customization of the system to their farm or ranch, and time for the practice to begin to have in impact on productivity. Meta-analysis of 12 data points from 7 sources shows that in the case of implementation of agroforestry solutions, net profits per hectare do not exceed business-as-usual for 6.1 years. To account for this delay in profitability, the Drawdown model assumes that net profit per hectare is 25% of the conventional rate until 6 years have elapsed.

### Other Inputs

Yield gains compared to conventional annual cropping systems were set at 31.1%, based on meta-analysis of 8 data points from 4 sources.

## Assumptions

Six overarching assumptions have been made for Project Drawdown models to enable the development and integration of individual model solutions: 1) infrastructure required for solution is available and in-place; 2) policies required are already in-place; 3) no carbon price is modeled; 4) all costs accrue at the level of agency modeled; 5) improvements in technology are not modeled; 6) first costs may change according to learning. Full details of core assumptions and methodology will be available at www.drawdown.org. Beyond these core assumptions, there are other important assumptions made for the modeling of this specific solution. These are detailed below:

1. Areas with 10-20 percent tree coverage is considered for this solution. It is assumed that other annual cropping solutions such as *conservation agriculture*, *regenerative agriculture*, *improved rice cultivation*, etc., will have some percentage of trees in their farms, but Drawdown models make the assumption that in these systems the proportion of trees remains under 10%. The area allocated for tree intercropping is thus separate from that allocated to these annual cropping based solutions, avoiding overlap and double-counting issues.
2. Carbon sequestration values included in this model are only derived specifically for *tree intercropping* system and do not include other solutions such as the ones listed above.
3. GHG emissions from tree intercropping systems are equal to those of annual cropping systems. This assumption is based on a meta-analysis by (Kim et al., 2016), which found no statistically significant difference in GHG emissions from tree intercropping systems and those from adjacent agricultural lands.

## Integration

The complete Project Drawdown integration documentation (will be available at [www.drawdown.org](http://www.drawdown.org)) details how all solution models in each sector are integrated, and how sectors are integrated to form a complete system. Those general notes are excluded from this document but should be referenced for a complete understanding of the integration process. Only key elements of the integration process that are needed to understand how this solution fits into the entire system are described here.

*Tree intercropping* is part of Drawdown’s Food sector, specifically the supply-side set that incorporate food production. Within agriculture it is part of a cluster of solutions based on annual crop production.

***The Agroecological Zone model***

Drawdown’s approach seeks to model integration between and within sectors, and avoid double counting. Several tools were developed to assist in this effort. The Agroecological Zone (AEZ) model categorizes the world’s land by: current cover (e.g. forest, grassland, cropland), thermal climate, moisture regime, soil quality, slope, and state of degradation.  Both Food (supply-side) and Land Use solutions were assigned to AEZs based on suitability. Once current solution adoption was allocated for each zone (e.g. semi-arid cropland of minimal slopes), zone priorities were generated and available land was allocated for new adoption. Priorities were determined based on an evaluation of suitability, consideration of social and ecological co-benefits, mitigation impact, yield impact, etc. For example, *Indigenous peoples’ land management* is given a higher priority than *forest protection* for AEZs with forest cover, in recognition of indigenous peoples’ rights and livelihoods. *Multistrata agroforestry* is highly prioritized in tropical humid climates due to its high sequestration rate, food production, and highly limited climate constraints.

Each unit of land was allocated to a separate solution to avoid overlap between practices. The exception to this are *farmland irrigation*, *nutrient management*, and *women smallholders*, which can be implemented in addition to other practices. The constraint of limited available land meant that many solutions could not reach their technical adoption potential. The AEZ model thus prevents double-counting for adoption of agricultural and land use solutions.

Drawdown’s agricultural production and land use model approach defines the Total Land Area as the area of land (in million hectares) suitable for adoption a given solution. Data on global land is acquired from Global Agro-Ecological Zones database, developed by the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA). The Drawdown Land-Use Model categorizes and allocates land according to agro-ecological zones based on the following factors: thermal climate, moisture regimes, soil quality, slope, cover type, and degradation status. These characteristics influence the suitability of different practices, and solution adoption scenarios are restricted by one or more of these factors.

Determining the total available land for a solution is a two-part process. The technical potential is based on: current land cover or land use; the suitability of climate, soils, and slopes; and on degraded or non-degraded status. In the second stage, land is allocated using the Drawdown Agro-Ecological Zone model, based on priorities for each class of land. The total land allocated for each solution is capped at the solution’s maximum adoption in the *Optimum* Scenario. Thus, in most cases the total available land is less than the technical potential.

***The Yield model***

Drawdown’s yield model calculates total annual global supply of crops and livestock products based on their area of adoption in each of the three scenarios, and global yield impacts of each solution (including both gains due to increased productivity per hectare and losses due to reduction of productive area due to adoption of non-agricultural solutions, e.g., loss of grazing area due to afforestation of grasslands). Grain surpluses in the yield model were also used to set a ceiling for the amount of crops available for use as feedstock for the *bioplastic* Materials solution.

The yield model matches demand and supply as an integrated system. Both *Reference* Scenarios showed a food deficit in the high and medium population scenarios (see *family planning*and *educating girls* solutions). This would require the clearing of forest and grassland for food production, with associated emissions from land conversion.

All three Drawdown scenarios show agricultural production sufficient to meet food demand and provide a surplus that can be used in bio-based industry, for example as feedstock for *bioplastic*production*.*Due to this surplus, no land clearing is necessary, resulting in impressive emissions reduction from avoided deforestation.  Because population change (resulting from *educating girls*and *family planning*),*plant-rich diet*, and *reduced food waste* are the principal drivers of this effect, Drawdown allocates the resulting reduction in emissions from land clearing to these solutions. However, as the impacts of population on yield and food demand are highly complex, we do not include avoided land conversion emissions associated with population change in the final emissions calculations for those solutions.

## Limitations/Further Development

In the absence of accurate satellite-based data on historical and current adoption at global scales, Drawdown figures for current adoption are based on estimates of tree cover on global agricultural land as reported by (Zomer et al., 2014). As global or regional projections of tree intercropping adoption in the future are similarly lacking, Drawdown predictions are based on: a) data collected by (Zomer et al., 2014) on tree cover in agricultural land, b) projections for tree intercropping adoption in the UK by 2050, as reported in (Thomson et al., 2018); and c) EU levels of current tree intercropping adoption in relation to total agricultural land area. While this approach may not accurately reflect local realities across different regions it provides an approximation of future tree intercropping adoption trends.

While this analysis synthesized the best available data, it is nevertheless limited by the scarcity of available empirical information regarding ecological and economic impacts and/or benefits of tree intercropping. Most importantly, there is currently very little understanding of how increased implementation of tree intercropping practices might change GHG emissions in annual cropping systems, nor of how quickly some of these systems may saturate aboveground and belowground carbon pools and cease to sequester additional carbon. Such dynamics are highly dependent on local conditions and therefore very difficult to accurately predict through a modeling framework. Studies to fill in these gaps in the data would significantly enhance future models.

Furthermore, extrapolating sequestration rates from the few areas represented in the literature we found to all global annual systems likely inaccurate. A more accurate approach might utilize earth systems models that model carbon pools based on localized data inputs, but such an approach is computationally intense and beyond the scope of our work. Similarly, financial components of Drawdown’s tree intercropping model were based on a limited number of studies from a limited number of areas. Since agricultural markets are highly localized, especially in communities where producers are primarily smallholders, access to markets, input costs, and prices differ broadly.

Given these limitations, Drawdown’s model outcomes should not be taken as completely accurate but as being indicative of the general scale and direction of *tree intercropping*’s drawdown capacity given current knowledge. In addition, calculations for this solution are limited to systems where tree intercropping is practiced in combination with tillage-based annual cropping. Combining tree intercropping with other “climate-friendly” practices such as conservation agriculture may well result in sequestration rates higher than either practice alone. This is an important area for future research.

# Results

## Adoption

Below are shown the world adoptions of the solution in some key years of analysis in functional units and percent for the three Project Drawdown scenarios.

Total adoption in the *Plausible* Scenario is 318.00 million hectares in 2050, representing 69 percent of the total suitable land. Of this, 70.00 million hectares are adopted from 2020-2050.

Total adoption in the *Drawdown* Scenario is 455.90 million hectares in 2050, representing 100 percent of the total suitable land. Of this, 207.90 million hectares are adopted from 2020-2050.

Total adoption in the *Optimum* Scenario is 440.50 million hectares in 2050, representing 96 percent of the total suitable land. Of this, 192.50 million hectares are adopted from 2020-2050.

**Table 3.1 World Adoption of the Solution**

| **Solution** | **Units** | **Base Year (2014)** | **New Adoption by 2050** | | |
| --- | --- | --- | --- | --- | --- |
| **Plausible** | **Drawdown** | **Optimum** |
| Tree intercropping | Mha | 248.00 | 70.00 | 207.90 | 192.50 |
| % Total Land Available (464 Mha) | 54% | 69.73% | 99.99% | 96.49% |

**Figure 3.1 World Annual Adoption 2020-2050 in Mha (a) and as a percentage of TLA (b).**

## Climate Impacts

Below are the emissions results of the analysis for each scenario which include total emissions reduction, atmospheric concentration changes, and sequestration where relevant. For a detailed explanation of each result, please see the glossary (Section 6).

Biosequestration impact is 13.71, 21.05 and 23.55 gigatons of carbon-dioxide equivalent in the *Plausible, Drawdown,* and *Optimum* Scenarios respectively.

**Table 3.2 Climate Impacts**

| **Scenario** | **Maximum Annual Emissions Reduction** | **Total Emissions Reduction** | **Max Annual CO2 Sequestered** | **Total Additional CO2 Sequestered** | **Total Atmospheric CO2-eq Reduction** | **Emissions Reduction in 2030** | **Emissions Reduction in 2050** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| *(Gt CO2-eq/yr.)* | *Gt CO2-eq/yr. (2020-2050)* | *(Gt CO2-eq/yr.)* | *Gt CO2-eq/yr. (2020-2050)* | Gt CO2-eq (2020-2050) | (Gt CO2-eq/year) | *(Gt CO2-eq/year)* |
| ***Plausible*** | 0.00 | 0.00 | 0.68 | 13.71 | 13.71 | 0.38 | 0.68 |
| ***Drawdown*** | 0.00 | 0.00 | 1.17 | 21.05 | 21.05 | 0.52 | 1.17 |
| ***Optimum*** | 0.00 | 0.00 | 1.08 | 23.55 | 23.55 | 0.72 | 1.08 |

The solution was integrated with all other Project Drawdown solutions and may have different emissions results from the models. This is due to adjustments caused by interactions among solutions that limit full adoption (such as by feedstock or demand limits) or that limit the full benefit of some solutions (such as reduced individual solution impact when technologies are combined).

**Table 3.3 Impacts on Atmospheric Concentrations of CO2-eq**

| **Scenario** | **GHG Concentration Change in 2050** | **GHG Concentration Rate of Change in 2050** |
| --- | --- | --- |
| *PPM CO2-eq (2050)* | *PPM CO2-eq change from 2049-2050* |
| **Plausible** | 1.16 | 0.05 |
| **Drawdown** | 1.79 | 0.09 |
| **Optimum** | 1.98 | 0.07 |

**Figure 3.2 World AnnualGreenhouse Gas Emissions Reduction**

## Financial Impacts

Below are the financial results of the analysis for each scenario. For a detailed explanation of each result, please see the glossary.

Note that the financial results have changed from those published in the first edition of the *Drawdown* book.

For the *Plausible* Scenario, cumulative first cost is US$136.86 billion. Marginal first cost is the same as cumulative first cost. Net operating savings is US$-358.90 billion. Net profit margin is US$183.31 billion, and lifetime profit margin is US$395.52. Lifetime cashflow savings NPV is $-98.53.

For the *Drawdown* Scenario, cumulative first cost is US$229.27 billion. Marginal first cost is the same as cumulative first cost. Net operating savings is US-550.93 billion. Net profit margin is US$259.50 billion, and lifetime profit margin is US$649.92 billion. Lifetime cashflow savings NPV is $-143.13 billion.

For the *Optimum* Scenario, cumulative first cost is US$224.30 billion. Marginal first cost is the same as cumulative first cost. Net operating savings is US$-616.41 billion. Net profit margin is US$330.15 billion, and lifetime profit margin is US$657.45 billion. Lifetime cashflow savings NPV is $-176.24 billion.

**Table 3.4 Financial Impacts**

| **Scenario** | **Cumulative First Cost** | **Marginal First Cost** | **Net Operating Savings** | **Net Profit Margin** | **Lifetime Profit Margin** | **Lifetime Cashflow Savings NPV (of All Implementation Units)** |
| --- | --- | --- | --- | --- | --- | --- |
| *2015-2050 Billion USD* | *2015-2050 Billion USD* | *2020-2050 Billion USD* | *2020-2050 Billion USD* | *2020-2050 Billion USD* | *Billion USD* |
| **Plausible** | $136.86 | $136.86 | $-358.90 | $183.31 | $395.52 | $-98.53 |
| **Drawdown** | $229.27 | $229.27 | $-550.93 | $259.50 | $649.92 | $-143.13 |
| **Optimum** | $224.30 | $224.30 | $-616.41 | $330.15 | $657.45 | $-176.24 |

***Figure 3.3 Net Profit Margin Increase***

## Other Impacts

The introduction of tree intercropping practices leads to significant yield increases 2020-2050 of 4,001.67, 6,134.95 and 6,879.35 million metric tons (including yields from tree and annual crop components), compared to sole conventional annual cropping, under the Plausible, Drawdown, and Optimum Scenarios respectively.

# Discussion

Results presented in this report suggest that tree intercropping systems have great C sequestration potentials, particularly in temperate climates where the amount of additional land available for tree intercropping systems is quite large and increased focus on conversion of annual cropland to intercropping might have significant impacts. On cropland with moderate to steep slopes or poor or degraded soils, tree intercropping is an important tool for slope stabilization and soil restoration. Tree intercropping combines the sequestration power of trees with the ability to continue producing the annual crops that humanity depend upon. If implemented more widely, this solution has the potential to significantly contribute to agricultural mitigation efforts.

Drawdown model estimates clearly indicate the importance of increasing adoption to make tree intercropping. Section 1.2 of this report highlights that increased integration of tree intercropping in national and regional strategies for “Climate-Smart Agriculture” has the potential of increasing adoption rates. This is already partially the case for the EU or individual countries like Rwanda, which have made steps to include tree intercropping in national policy frameworks. More widespread recognition of the solution’s potential, and integration of tree intercropping practices into national land-use strategies could increase the Drawdown impact of tree intercropping globally for instance. For instance, this could be include promoting similar programming that is locally relevant in target areas where adoption is currently low.

Despite significant knowledge gaps in the literature, and inherent limitations in Drawdown’s modeling framework, the results presented in this report outline the general magnitude and direction of tree intercropping’s potential, given current estimates of adoption rates. The results presented here further highlight the practice’s significant potential in the case of widespread, rapid adoption. As such, tree intercropping appears to be a system that warrants more attention and should be more strongly supported and promoted by stakeholders.

## Limitations

A few key gaps nonetheless remain in the literature on tree intercropping; addressing them would increase the accuracy of Drawdown projections. Studies comparing the financial advantages of converting annual cropping systems to tree intercropping remain scarce. More data documenting the impacts of different sub-types of tree intercropping systems, in different climates and across different cropping arrangements, would significantly increase the relevance of Drawdown’s conclusions. More accurate data on current adoption extent is also currently lacking.

## Benchmarks

Benchmarks for the climate change mitigation impact of *tree intercropping* are rare, as it is typically considered part of an undifferentiated “agroforestry” solution, if at all. Still, a recent study by (Lal et al., 2018) estimates a range between 0.40 – 1.55 MgC/ha/year for all global tree intercropping systems, and a study by (Griscom et al., 2017) estimates the C sequestration potential of all tree intercropping systems at 0.37 MgC/ha/year. There is a scarcity of benchmarks specific to tree intercropping sub-types, although (Udawatta and Jose, 2011) estimate the total sequestration potential of alley cropping at 3.4 MgC/ha/year. Annual impact of tree intercropping in 2030 is 0.50 – 1.29 gigatons of carbon dioxide equivalent per year. Thus, though an imperfect benchmark, this study is generally on target.

**Table 4.1 Benchmarks**

| **Source and Scenario** | **New Adoption** | **Mitigation Impact**  **Gt CO2-eq in 2030** |
| --- | --- | --- |
| Udawatta & Jose (2011) | n/a | 3.4 |
| Lal et al. (2018) | n/a | 0.40 – 1.55 |
| Griscom et al. (2017) | n/a | 0.37 |
| *Plausible* Scenario | 70.00 | 0.38 |
| *Drawdown* Scenario | 207.90 | 0.52 |
| *Optimum* Scenario | 192.50 | 0.72 |

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# Glossary

**Adoption Scenario** – the predicted annual adoption over the period 2015 to 2060, which is usually measured in **Functional Units**. A range of scenarios is programmed in the model, but the user may enter her own. Note that the assumption behind most scenarios is one of growth. If for instance a solution is one of reduced heating energy usage due to better insulation, then the solution adoption is translated into an increase in use of insulation. There are two types of adoption scenarios in use: **Reference (REF)** where global adoption remains mostly constant, and **Project Drawdown Scenarios (PDS)** which illustrate high growth of the solution.

**Approximate PPM Equivalent** – the reduction in atmospheric concentration of CO2 (in **PPM**) that is expected to result if the **PDS Scenario** occurs. This assumes a discrete avoided pulse model based on the Bern Carbon Cycle model.

**Average Abatement Cost** – the ratio of the present value of the solution (**Net** **Operating Savings** minus **Marginal First Costs**) and the **Total Emissions Reduction**. This is a single value for each solution for each **PDS Scenario**, and is used to build the characteristic “*Marginal Abatement Cost*” curves when Average Abatement Cost values for each solution are ordered and graphed.

**Average Annual Use** – the average number of functional units that a single implementation unit typically provides in one year. This is usually a weighted average for all users according to the data available. For instance, total number of passenger-km driven by a hybrid vehicle in a year depends on country and typical number of occupants. We take global weighted averages for this input. This is used to estimate the **Replacement Time**.

**Cumulative First Cost** – the total **First Cost** of solution **Implementation Units** purchased in the **PDS Scenario** in the analysis period. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

**Direct Emissions** – emissions caused by the operation of the solution, which are typically caused over the lifetime of the solution. They should be entered into the model normalized per functional unit.

**Discount Rate**- the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows. The discount rate in DCF analysis takes into account not just the time value of money, but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate. Most importantly, the greater the discount rate, the more the future savings are devalued (which impacts the financial but not the climate impacts of the solution).

**Emissions** **Factor**– the average normalized emissions resulting from consumption of a unit of electricity across the global grid. Typical units are kg CO2e/kWh.

**First Cost**- the investment cost per **Implementation Unit** which is essentially the full cost of establishing or implementing the solution. This value, measured in 2014$US, is only accurate to the extent that the cost-based analysis is accurate. The financial model assumes that the first cost is made entirely in the first year of establishment and none thereafter (that is, no amortization is included). Thus, both the first cost and operating cost are factored in the financial model for the first year of implementation, all years thereafter simply reflect the operating cost until replacement of the solution at its end of life.

**Functional Unit** – a measurement unit that represents the value, provided to the world, of the function that the solution performs. This depends on the solution. Therefore, LED Lighting provides petalumen-hours of light, Biomass provides tera-watt-hours of electricity and high speed rail provides billions of passenger-km of mobility.

**Grid Emissions** – emissions caused by use of the electricity grid in supplying power to any operation associated with a solution. They should be in the units described below each variable entry cell. Drawdown models assume that the global electric grid, even in a Reference Scenario, is slowly getting cleaner, and that emissions factors fall over time resulting in lower grid emissions for the same electricity demand.

**Implementation Unit** – a measurement unit that represents how the solution practice or technology will be installed/setup and priced. The implementation unit depends on the solution. For instance, implementing electric vehicles (EV) is measured according to the number of actual EV’s in use, and adoption of Onshore Wind power is measured according to the total terawatts (TW) of capacity installed worldwide.

**Indirect Emissions** – emissions caused by the production or delivery or setup or establishment of the solution in a specified area. These are NOT caused by day to day operations or growth over time, but they should be entered into the model normalized on a per functional unit or per implementation unit basis.

**Learning Rate/Learning Curve** - Learning curves (sometimes called experience curves) are used to analyze a well-known and easily observed phenomenon: humans become increasingly efficient with experience. The first time a product is manufactured, or a service provided, costs are high, work is inefficient, quality is marginal, and time is wasted. As experienced is acquired, costs decline, efficiency and quality improve, and waste is reduced. The model has a tool for calculating how costs change due to learning. A 2% learning rate means that the cost of producing a *good* drops by 2% every time total production doubles.

**Lifetime Capacity** – this is the total average functional units that one implementation unit of the solution or conventional technology or practice can provide before replacement is needed. All technologies have an average lifetime usage potential, even considering regular maintenance. This is used to estimate the **Replacement Time**. and has a direct impact on the cost to install/acquire technologies/practices over time. E.g. solar panels generate, on average, a limited amount of electricity (in TWh) per installed capacity (in TW) before a new solar panel must be purchased. Electric vehicles can travel a limited number of passenger kilometers over its lifetime before needing to be replaced.

**Lifetime Operating Savings**–the operating cost in the PDS versus the REF scenarios over the lifetime of the implementation units purchased during the model period regardless of when their useful life ends.

**Lifetime Cashflow NPV**-the present value (PV) of the net cash flows (PDS versus REF) in each year of the model period (2015-2060). The net cash flows include net operating costs and first costs. There are two results in the model: Lifetime Cashflow NPV for a Single **Implementation Unit**, which refers to the installation of one **Implementation Unit**, and Lifetime Cashflow NPV of All Units, which refers to all **Implementation Units** installed in a particular scenario. These calculations are also available using profit inputs instead of operating costs.

**Marginal First Cost** – the difference between the **First Cost** of all units (solution and conventional) installed in the **PDS Scenario** and the **First Cost** of all units installed in the **REF Scenario** during the analysis period. No discounting is performed. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

**Net Annual Functional Units (NAFU)** – the adoption in the PDS minus the adoption in the REF in each year of analysis. In the model, this represents the additional annual functional demand captured either by the solution in the **PDS Scenario** or the conventional in the **REF Scenario**.

**Net Annual Implementation Units (NAIU)** – the number of **Implementation Units** of the solution that are needed in the PDS to supply the **Net Annual Functional Units (NAFU).** This equals the adoption in the PDS minus the adoption in the REF in each year of analysis divided by the average annual use.

**Net Operating Savings** – The undiscounted difference between the operating cost of all units (solution and conventional) in the **PDS Scenario** minus that of all units in the **REF Scenario**.

**Operating Costs** – the average cost to ensure operation of an activity (conventional or solution) which is measured in 2014$US/**Functional Unit**. This is needed to estimate how much it would cost to achieve the adoption projected when compared to the **REF Case**. Note that this excludes **First Costs** for implementing the solution.

**Payback Period** – the number of years required to pay all the **First Costs** of the solution using **Net Operating Savings**. There are four specific metrics each with one of **Marginal First Costs** or **First Costs** of the solution only combined with either discounted or non-discounted values. All four are in the model. Additionally, the four outputs are calculated using the increased profit estimation instead of **Net Operating Savings**.

**PDS/ Project Drawdown Scenario** – this is the high growth scenario for adoption of the solution

**PPB/ Parts per Billion** – a measure of concentration for atmospheric gases. 10 million PPB = 1%.

**PPM/ Parts per Million** – a measure of concentration for atmospheric gases. 10 thousand PPM = 1%.

**REF/ Reference Scenario** – this is the low growth scenario for adoption of the solution against which all **PDS scenarios** are compared.

**Regrets solution** has a positive impact on overall carbon emissions being therefore considered in some scenarios; however, the social and environmental costs could be harmful and high.

**Replacement Time**- the length of time in years, from installation/acquisition/setup of the solution through usage until a new installation/acquisition/setup is required to replace the earlier one. This is calculated as the ratio of **Lifetime Capacity** and the **Average Annual Use**.

**TAM/ Total Addressable Market** – represents the total potential market of functional demand provided by the technologies and practices under investigation, adjusting for estimated economic and population growth. For this solutions sector, it represents world and regional total addressable markets for electricity generation technologies in which the solutions are considered.

**Total Emissions Reduction** – the sum of grid, fuel, indirect, and other direct emissions reductions over the analysis period. The emissions reduction of each of these is the difference between the emissions that would have resulted in the **REF Scenario** (from both solution and conventional) and the emissions that would result in the **PDS Scenario**. These may also be considered as “emissions avoided” as they may have occurred in the REF Scenario, but not in the PDS Scenario.

**Transition solutions** are considered till better technologies and less impactful are more cost effective and mature.

**TWh/ Terawatt-hour** – A unit of energy equal to 1 billion kilowatt-hours

1. For most results, only the differences between scenarios, summed over 2020-2050 were presented, but for the net first cost, the position was taken that to achieve the adoptions in 2020, growth must first happen from 2015 to 2020, and that growth comes at a cost which should be accounted for, hence net first cost results represent the period 2015-2050. [↑](#footnote-ref-1)
2. Current adoption is defined as the amount of land area adopted by the solution in 2018. This study uses 2014 as the base year due to the availability of global adoption data for all Project Drawdown solutions evaluated.  [↑](#footnote-ref-2)
3. In some cases, the low boundary is negative for a variable that can only be positive, and in these cases the lowest collected data point is used as the “low” boundary. [↑](#footnote-ref-3)